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HUMAN-BIOMETEOROLOGICAL ASSESSMENT OF KHARKIV (UKRAINE) IN THE SUMMER SEASON

Ocjena ljetnih biometeoroloških prilika u Harkovu (Ukrajina)

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Abstract: The objective of this research is to assess the bioclimate of the city of Kharkiv in the summer season using the human thermal index of physiologically equivalent temperature (PET). The RayMan model has been used to obtain PET values. The results suggest that most days in Kharkiv during the summer are characterized by heat stress of various intensity – 65.7% in June, 84.6% in July, 77.1% in August. The average frequency of comfortable weather is very low, varying from 12.6 to 25%. During heat waves, the frequency of days in Kharkiv with heat stress increases significantly, amounting to 96.3%. The results of the Kharkiv bioclimate assessment using PET may be used to create measures for heat adaptation and develop infrastructure for recreation and tourism in the city during hot periods.

Key words: bioclimate, physiologically equivalent temperature (PET), thermal comfort, heat stress, heat wave, RayMan model

Sažetak: Cilj je ovim istraživanjem odrediti ljetnu bioklimu grada Harkova s pomoću biometeorološkog indeksa osjeta ugode PET (fiziološka ekvivalentna temperatura). Za izračun PET indeksa upotrijebljen je RayMan model. Rezultati pokazuju da je u većini ljetnih dana u Harkovu prisutan toplinski stres; u lipnju 65,7 % dana, u srpnju 84,6 % dana te u kolovozu 77,1 % dana. Srednja čestina ugodnog vremena je vrlo mala, između 12,6 % i 25 %. Tijekom toplinskih valova čestina dana s toplinskim stresom znatno raste, čak do 96,3 %. Rezultati ocjene bioklimatskih prilika u Harkovu s pomoću PET indeksa mogu služiti za razvoj mjera prilagodbe na toplinski stres te razvoj infrastrukture za rekreaciju i turizam u gradu tijekom toplinskih valova.

Ključne riječi: bioklima, fiziološka ekvivalentna temperatura (PET), osjet ugode, toplinski stres, toplinski val, RayMan model

1. INTRODUCTION

Due to recent climate trends, most of the world's population has become more vulnerable to heat stress. In recent decades, observed climate trends show an increase in air temperature across Europe (IPCC, 2007), including Ukraine (Balabukh and Lukianets, 2015). Ukrainian climate studies suggest that both air temperature and the frequency of heat wave cases (HWs) have increased in Ukraine in recent decades (Shevchenko et al., 2014).

The negative health effects of heat can include cramps, heat exhaustion, heat edema and heat rush, heatstroke, dehydration, disease exacerbations, the combined effect of medications on thermoregulation, heat fainting, and even mortality (McGregor et al., 2015; Ebi et al., 2011). Severe dehydration caused by extreme heat leads to acute cerebrovascular accidents and can contribute to thrombogenesis. It can further aggravate chronic pulmonary conditions, cardiac conditions, kidney disorders, and psychiatric illness (McGregor et al., 2015). Most heat-related deaths are tied to the worsening of the pre-existing health conditions mentioned above, while comparatively significantly fewer deaths and illnesses are directly caused by heat (heatstroke). The health effects of heat on individuals can differ significantly due to a range of heat-risk factors.

Populations vulnerable to high air temperature include the elderly (most studies use a 65-year threshold), the socially isolated, the chronically ill, the homeless, the mentally ill, and some other groups (Schuster et al., 2014; Ebi et al., 2011; Kovats and Ebi, 2006; Cusack et al., 2011). The adverse effects of heat in large cities are attributed to the increased elderly population and increased urbanization. Specific microclimatic features in an urbanised environment lead to local temperature increases in city centres; urban residents thus suffer even higher heat stress than the residents of adjacent rural areas. Combined with climate change, the heat island effect makes urban environments more vulnerable to extremely high air temperatures (Ebi et al., 2011; D'Ippoliti et al., 2010; Coutts et al., 2007).

According to official data, Kharkiv is the second largest city in Ukraine with about 1.5 million residents and a very high population density of 3,900 km^{-2}. In addition, Kharkiv was one of the top three Ukrainian cities visited by foreign tourists in 2018, with over 1.2 million foreigners and more than 5 million Ukrainian tourists visiting the city. In summer, residents of and visitors to Kharkiv may be exposed to heat stress when outdoors, since the average air temperature in June–August from 1991–2014 increased by 1.1°C as compared to the normal climatic period; the frequency of heat wave episodes in the summer months also increased significantly (Svintsitska and Shevchenko, 2017).

Therefore, thermal comfort conditions during the summer months and HW periods in Kharkiv are of considerable scientific and practical interest. In fact, the results can be used to increase the comfort of a significant number of people living and staying in the city by allowing them to select the optimum time to visit the city, as well as to develop recreation and tourism infrastructure in the city during heat periods and design and implement heat adaptation measures. A thorough analysis of sectoral adaptation actions, measures, and policies undertaken by national governments in a selection of 11 South East European countries (including Ukraine) was performed by Pietrapertosa et al. (2018) under the OrientGate project. According to the results of analysis, Ukraine implemented National Action Plans and began implementing a national adaptation strategy. The water sector, agriculture, and urban adaptation and health are the priority sectors Ukraine addresses in the national adaptation actions. Heat stress is usually one of the main potential climate change consequences for urban areas. Thus, the results of research into Kharkiv's thermal comfort conditions during the summer months could be very useful in preparing city and regional adaptation plans.

The purpose of this study is to assess the bioclimate of the city of Kharkiv during the calendar summer using a modern thermal index and the RayMan model to obtain values.

Figure 1. Kharkiv's location.

Slika 1. Položaj grada Harkova.

2. METHODOLOGY

2.1. Site description

The research was carried out in Kharkiv, Ukraine (50° 00′ 21″ N, 36° 13′ 45″ E; from 95 to 205 m elevation) (Fig. 1).

According to Köppen-Geiger's climate classification, Kharkiv has a humid continental climate (Dfb) with cold, snowy winters and dry, hot summers (Kottek et al., 2006). The mean annual air temperature is 7.5°C and annual rainfall is 525 mm. The annual mean wind speed is 4.0 ms^{-1} and annual sunshine duration is 1,776 hours. The mean air temperature of the calendar summer (June–August) is 19.6°C (Klimatychnyi kadastr Ukrainy, 2006) and mean maximum air temperature for this period is 25.0°C. The number of days with air temperatures above 30.0°C during the summer months reaches 15 on average.

2.2. Data

To estimate the bioclimatic conditions of Kharkiv, daily air temperature, relative humidity, cloudiness and wind speed data were used from the Kharkiv Meteorological Station at 12:00 UTC for the period from June 1 to August 31, 2005–2014. Observations conducted at the station are not automated. Observational instruments and methods are in line with WMO requirements: ordinary (station) mercury-in-glass-type thermometer for air temperature measurements, a psychrometer for air humidity, and propeller anemometers for wind speed. Cloudiness is determined by visual observation.

Time series of daily maximum air temperature in the summer months of June to August from 1961 to 1990 and from 2005 to 2014 were used to determine HW cases in Kharkiv according to the definition recommended by the IPCC.

2.3. Methods

The first bioclimatic studies of the territory of Ukraine were undertaken in the late 1970s and are still being carried out by various researchers. Unfortunately, today's bioclimate assessment in Ukraine actively uses the simplest bioclimatic indices, most of which were developed over fifty years ago. These indices are very simple to calculate, mainly taking into account the effect of meteorological parameters on human thermal perception, while indices based on the human body energy balance have been used throughout the world for bioclimatic assessments over the last few decades. One of the most popular indices among European scientists is physiologically equivalent temperature (PET) (Mayer and Hoppe, 1987; Hoppe, 1999). An analysis of the frequency of thermal indices used in the reviewed studies shows that PET was used in 30.2% of case studies (Potchter et al., 2018). Physiologically equivalent temperature can be used for any climate, both as a standard parameters of the person as well as for each individual. The benefits and versatility of PET are apparent not only in its widespread use by meteorological scientists, but also in the fact that Directive No. 3787 of the Association of German Engineers (Verein Deutscher Ingenieure, VDI), Part II of "Methods for the human-biometeorological evaluation of climate and Air Quality for Urban and Regional Planning, Part I: Climate" (VDI, 1998) recommends the use of PET for the evaluation of thermal components of different climates. Shevchenko (2016) presents the results of a comparison of the bioclimatic indices most commonly used on the territory of Ukraine with PET, along with a detailed description and substantiation of the latter's advantages.

To date, PET has been used to assess bioclimate for different parts of our planet – Germany (Ketterer and Matzarakis, 2014), Poland (Błażejczyk and Matzarakis, 2007), Nigeria (Omonijo et al., 2013), China (Lin and Matzarakis, 2011), Hungary (Gulyás and Matzarakis, 2009), and Brazil (Abreu-Harbich et al., 2014). In Ukraine, a bioclimate study using PET has only been undertaken for Odessa (Katerusha and Matzarakis, 2015) and Kyiv (Shevchenko and Baidyuk, 2016).

The RayMan model (Matzarakis and Rutz, 2005; Matzarakis et al., 2010) was used to obtain the values of the bioclimatic index of physiologically equivalent temperature.

The following data groups are used to simulate PET values in the RayMan model:

I. Date and time. First, we indicate the date and time for which we must calculate thermal indices.
II. Data that characterise the locations of observations, such as geographical coordinates, altitude and time zone.
III. Meteorological data: air temperature (°C), vapour pressure (hPa), or relative humidity (%), wind speed (ms^{-1}) and the degree of cloud cover (oktas).
IV. The morphophysiological parameters of a person and parameters that can affect heat sensation (clothing and activity).

Since we performed our PET calculations in order to generally characterise the bioclimate of Kharkiv during the summer period, and not to study the thermal comfort of a specific individual with certain morphophysiological parameters under certain conditions, the simulations used standard parameters of a hypothetical individual: 35-year-old male, 1.75 m in height, 75 kg in weight, wearing clothing with a heat resistance of 0.9 clo, sedentary, with heat production equivalent to 80 W.

2. RESULTS AND DISCUSSION

As noted above, one of the most popular thermal indices among European scientists today is physiologically equivalent temperature based on the energy balance of the human body. PET is defined as the physiological equivalent temperature at any given place and is equivalent to the air temperature at which the heat balance of the human body (work metabolism 80 W of light activity, added to basic metabolism; heat resistance of clothing 0.9 clo) is maintained in a typical indoor setting, with core and skin temperatures equal to those under the conditions being assessed. The following assumptions are made for the indoor reference climate: mean radiant temperature equals air temperature, wind speed is set to 0.1 ms^{-1}, water vapour pressure is set to 12 hPa (which

Table 1. Ranges of physiologically equivalent temperature (PET) for different grades of thermal perception by human beings and physiological stress on human beings (Matzarakis et al., 1999).

Tablica 1. Raspon fiziološke ekvivalentne temperature (PET) za različite stupnjeve osjeta ugode i fiziološkog stresa (Matzarakis et al., 1999).

PET (°C)	Thermal perception	Grade of physiological stress
4	Very cold	Extreme cold stress
4.1–8.0	Cold	Strong cold stress
8.1–13.0	Cool	Moderate cold stress
13.1–18.0	Slightly cool	Slight cold stress
18.1–23.0	Comfortable	No thermal stress
23.1–29.0	Slightly warm	Slight heat stress
29.1–35.0	Warm	Moderate heat stress
35.1–41.0	Hot	Strong heat stress
>41.1	Very hot	Extreme heat stress

is approximately equal to a relative humidity of 50% at Ta=20°C) (Hoppe, 1999). The PET units are °C, which makes this index very easy to use. Comfortable conditions correspond to PET values within the range of 18.1–23.0°C (Tab. 1).

The basis for calculating the physiologically equivalent temperature is the Munich Energy Balance Model for Individuals (MEMI).

In bioclimatology, the averaged values of the thermal index can sometimes be used to assess the effects of climate on the human body. However, since different thermal indices have different units of measure, a different number of gradations to determine the comfort/discomfort of an environment and other differences, the numerical expression of the thermal index alone is not always representative and, moreover, the numerical values of different thermal indices cannot be compared. The most commonly obtained values of thermal indices for a given period are attributed to a grade of physiological stress (e.g. comfortable weather, weather with heat stress, etc.) and are used to calculate the frequency of days pertaining to that grade for a selected time period. This is exactly the approach we took in this paper to characterize the bioclimate of Kharkiv.

The calculated PET values for Kharkiv for the researched period are in the range of 10.1–42.9°C. The PET values within this range fall into 7 grades: from moderate cold stress (observed on 5 days) to extreme heat stress (7 days). The frequency of comfortable weather in the summer months in Kharkiv is unfortunately not very high, varying from 12.6% in July to 25% in June (Fig. 2).

The average frequency of days with cold stress in the period from 2005–2014 amounts to 9.3% in June, 2.9% in July, and 5.2% in August. It should be noted that these are predominantly days with slight cold stress, which, given the proper choice of clothing, cannot cause significant harm to the human body. Additionally, days with cold stress were not recorded during summer months in the researched period (August 2005, July 2008, July 2010, June and July 2011, July and August 2014).

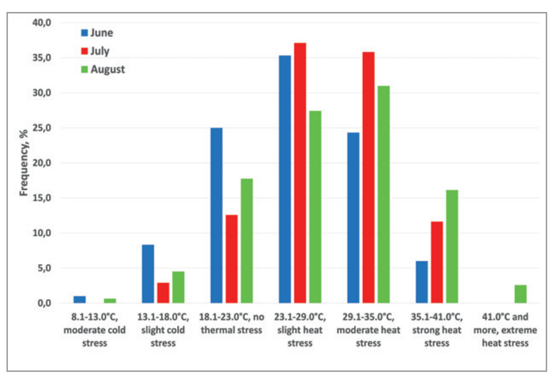

Figure 2. The mean frequency of occurrence of different physiologically equivalent temperature clases (°C) at 12:00 UTC in Kharkiv for the period 2005–2014.

Slika 2. Srednja učestalost pojedinih stupnjeva fiziološke ekvivalentne temperature (°C) u 12.00 UTC u Harkovu, u razdoblju 2005. – 2014.

The mean frequency of days with heat stress in Kharkiv is high: 65.7% in June, 84.6% in July, and 77.1% in August. However, extreme heat stress posing the greatest danger to human health and life was recorded only in August at a frequency of 2.6%. Strong heat stress was observed in all summer months. The lowest frequency of heat stress was naturally recorded during the coldest summer month, June, amounting to 6%; in July and August it was 11.6% and 16.1%, respectively. The higher frequency of days with strong heat stress in August during the research period was due to an intense heat wave in 2010, which began on 30 July and ended on 18 August.

During the summer months, slight and moderate heat stress show the highest frequency; jointly accounting for almost 60% of days in June and August and nearly 73% in July.

Thermal comfort conditions observed in Kharkiv are somewhat more comfortable than in Kyiv in almost all summer months (Tab. 2). In Kharkiv, the frequency of comfortable weather is 5% higher than in Kyiv in June and 2% higher in July. In August, the figure is the same for both cities. The frequency of heat stress in Kharkiv in June and July is lower than in Kyiv, as is the frequency of cold stress in July and August. However, it should be noted that differences in the frequency of various grades of physiological stress between the two cities are not very significant (lower or equal to 5%).

A human thermal bioclimate assessment for another Ukraininan city – Odessa – was undertaken by Katerusha and Matzarakis (2015). The research was also based on physiological equivalent temperature and the RayMan model was used to obtain PET values. Odessa (46° 25′ N, 30° 45′ E; elevation 40 m) is located on the Black Sea coast in the southwest of Ukraine. Odessa has a warm temperate climate (Cfb), fully humid, with warm summers. The annual average temperature is 10.3°C, which is nearly 3°C higher than in Kharkiv. Heat stress in Odessa prevails from the last 10 days of June to the end of August (Katerusha and Matzarakis, 2015). The frequency of days with heat stress in Odessa is significantly higher than in Kharkiv. The mean frequency of days with strong and extreme heat stress (PET>35.0°C) in Odessa reaches about 14% in June, 41% in July, and 47% in August, which is more than twice as high as in Kharkiv (6% in June, 11.6% in July, and 18.7% in August).

Heat wave is an atmospheric phenomenon of a synoptic scale that manifests as a period of abnormally hot weather with a duration of at least few days, usually with a discernible impact on human and natural systems. Due to global climate change, the frequency of heat wave episodes is increasing significantly worldwide, including Ukraine. As air temperature is one of the main parameters affecting human thermal comfort, it is normal for bioclimatic conditions to deteriorate significantly during heat waves, exposing the population to considerable heat stress.

Table 2. The frequency (%) of days with comfortable weather, heat and cold stress in Kharkiv and Kyiv, and their differences ($\Delta_{Kh\text{-}K}$) for the period 2005–2014.

Tablica 2. Učestalost (%) ugodnih, vrućih i hladnih dana u Harkovu i Kijevu i njihove razlike ($\Delta_{Kh\text{-}K}$) u razdoblju 2005. – 2014.

Grade of physiological stress	Month	Kharkiv	Kyiv	$\Delta_{Kh\text{-}K}$
Cold stress	June	9.3%	10.0%	-0.7%
	July	2.9%	2.6%	0.3%
	August	5.2%	7.1%	-1.9%
No thermal stress	June	25.0%	20.0%	5.0%
	July	12.6%	10.6%	2.0%
	August	17.8%	17.8%	0.0%
Heat stress	June	65.7%	70.0%	-4.3%
	July	84.6%	86.8%	-2.2%
	August	77.1%	75.1%	2.0%

So far, there is no single universal definition of heat waves to be used as a criterion to detect this anomaly in all studies without exception. However, Shevchenko and Snizhko (2012) substantiate the convenience of using the HW definition recommended by the Intergovernmental Panel on Climate Change (IPCC) to study this atmospheric phenomenon in the territory of Ukraine. According to this definition, a heat wave is a period of more than 5 consecutive days with a daily maximum air temperature more than 5°C above the mean daily maximum air temperature at a given station for the normal climatic period from 1961–1990 (Radinović and Ćurić, 2012). Numerous studies show that the number of HW events has been increasing worldwide in recent decades. Kharkiv is also characterized by an increase in the frequency of heat wave occurrence: this phenomenon was recorded 17 times in the summer months June to August in the period 1991–2015. From 2005–2014, based on the HW definition recommended by the IPCC, 12 HW events were identified in Kharkiv (Tab. 3).

The duration and intensity of a HW are very important characteristics of this meteorological phenomenon. The duration of HWs observed from 2005 to 2014 in Kharkiv ranged from 6 to 20 days (Tab. 3). To characterize the intensity of a HW, cumulative $T_{A,MAX}$ excess was applied. According to Kyselý (2002), this is the most appropriate parameter for this purpose. Usually, the cumulative $T_{A,MAX}$ excess during a single HW is calculated as the sum of the difference between the maximum daily air temperature and a threshold value, which depends on the heat wave definition. Table 3 presents the intensity characteristics of the HW events detected from 2005 to 2014.

Table 3. Characteristics of heat wave events in Kharkiv in the summer months in the period 2005–2014.

Tablica 3. Termalni uvjeti tijekom toplinskih valova u Harkovu tijekom ljetnih mjeseci u razdoblju 2005. – 2014.

Date	Cumulative T_{MAX} excess (°C)	Duration (days)
12.8.–19.8.2006.	18.3	8
17.8–26.8.2007.	54.9	10
12.8–19.8.2008.	38.1	8
22.6–27.6.2009.	12.5	6
15.7–20.7.2009.	24.5	6
9.6–14.6.2010.	18.5	6
24.6–29.6.2010.	15.0	6
16.6–24.6.2010.	29.5	9
30.7–18.8.2010.	117.0	20
10.6–15.6.2012.	20.8	6
25.7–8.8.2012.	44.7	15
11.6–17.6.2013.	12.0	7

Duration and intensity cannot fully reflect the degree of adverse effects the HW has on the human body. In order to address this, PET values during the HW episodes observed in Kharkiv from 2005 to 2014 were analysed in this study. The PET values simulated for the researched HW events were ranged from 24.2 to 42.9°C, thus corresponding to the grades of slight, moderate, severe, and extreme heat stress (Tab. 4). Simultaneously, within the 107 days when a HW was observed, only 4 (3.7% of the total duration of HW) were characterised by a PET value below 29.0°C, which corresponds to slight thermal stress. Most often, days with severe heat stress were recorded during heat waves – 51.4%; 37.4% of days had moderate heat stress, 7.5% of days had extreme heat stress; these were recorded only during the HW in August 2007 and during the HW in late July/early August 2010.

The most unfavorable conditions for the residents of the city were observed during the heat wave in late July/early August 2010. This HW was not only characterized by extreme heat stress, but was also the longest and the most intense in Kharkiv since 1936 (Shevchenko et al., 2014). During this heat wave, which began in Kharkiv on 30 July and ended on 18 August, the mean daily air temperature was very high, with the maximum temperature exceeding the mean maximum air temperature for a given day by 5.1–13.2°C as compared to the normal climatic period (1961–1990). During the heat wave, the maximum daily air temperature exceeded 37.0°C twelve times, four times of which the maximum temperature exceeded 39.0°C. The minimum daily air temperature was also notably higher and ranged from 17.3–26.0°C, with only 3 days during the HW with a minimum temperature below 20.0°C. If minimum air temperature is above 20°C, nights are considered tropical (TR20). Tropical nights are a part of basic climate change indices, the study of which has been proposed by the World Meteorological Organization (WMO) and the Expert Team on Climate Change Detection and Indices (ETCCDI) (Elizbarashvili et al., 2017). Thus, 17 tropical nights were observed during the 20-day heat wave in July–August 2010. It should be noted that the amount of TR20 in Kharkiv has changed from 48 for the period 1971–1990 to 174 for the period 1991–2010.

The heat wave of 2010, the majority of which took place in Kharkiv in August, also caused a significant difference between the average temperature of this month in 2010 and the normal climatic period; this difference amounted to 6.1°C, while it was -0.5°C for August 2009 and 1.5°C for August 2011.

Daily PET values at 12:00 UTC during this HW fluctuated from 38.7°C to 42.9°C; these fall within the "severe" and "extreme" heat stress grades, and were significantly higher than the ten-year (2005–2014) average PET values for each of these days (Fig. 3). The maximum physiologically equivalent temperature during this HW (42.9°C) was recorded on 5 August. The average PET values for 2005–2014 were ranged from 28.1–33.2°C, corresponding with the "moderate" and "slight" heat stress grades. The differences between daily PET values during the HW in late July/early August 2010 and the mean values for 2005–2014 for the same days varied from 1.9 to 13.6°C, with only 3 days displaying differences lower than 5°C.

It should be noted that the heat wave in late July/early August 2010 covered a large part of the territory of Ukraine. It started from Luhansk on 26 July, covered all other stations of the eastern, central, and southern part of Ukraine (with the exception of Odessa, which it only reached on 5 August) by 30–31 July. The HW ended on 16–18 August. For Kyiv, it was the longest and the most severe heat wave since 1911 (18 days, cumulative $T_{A,MAX}$=108.6°C) (Shevchenko, 2013). Although the intensity and duration of this HW was higher in Kharkiv (20 days, cumulative $T_{A,MAX}$ = 117.0°C), the intensity of heat stress during the heat wave was slightly higher in Kyiv. The mean PET value during the HW period in Kyiv was 42.2°C and the PET value ranged from 37.0 to 47.0°C; for Kharkiv, the mean PET value during this HW was 39.5°C and the PET value range was 33.1–42.9°C (Fig. 4). An analysis of differences in PET values between the two cities shows that, in the vast majority of cases (72.2%), higher values of this bioclimatic index were observed in Kyiv. On individual days, the differences were minor (less than 1°C), but on some days the differences exceeded 7°C (with a maximum value of 9.5°C).

Table 4. Thermal conditions during heat wave events in Kharkiv in the summer months over the period 2005–2014.

Tablica 4. Termalni uvjeti tijekom toplinskih valova u Harkovu tijekom ljetnih mjeseci u razdoblju 2005. – 2014.

Date and duration (days)	Mean PET (°C) values during the HW period	Range of PET values (°C) during the HW
12.8.–19.8.2006 (8)	34.7	30.5 (moderate HS) – 39.6 (strong HS)
17.8.–26.8.2007 (10)	36.7	31.7 (moderate HS) – 41.2 (extreme HS)
12.8.–19.8.2008 (8)	37.4	34.1 (moderate HS) – 40.3 (strong HS)
22.6.–27.6.2009 (6)	33.8	31.1 (moderate HS) – 40.7 (strong HS)
15.7.–20.7.2009 (6)	35.6	24.2 (slight HS) – 39.1 (strong HS)
9.6.–14.6.2010 (6)	34.3	32.0 (moderate HS) –36.8 (strong HS)
24.6.–29.6.2010 (6)	32.9	28.3 (slight HS) – 36.8 (strong HS)
16.6.–24.6.2010 (9)	35.4	30.9 (moderate HS) – 39.2 (strong HS)
30.7.–18.8.2010 (20)	39.5	33.1 (moderate HS) – 42.9 (extreme HS)
10.6.–15.6.2012 (6)	33.8	31.0 (moderate HS) –37.4 (strong HS)
25.7.–8.8.2012 (15)	35.3	31.7 (moderate HS) –36.4 (strong HS)
11.6.–17.6.2013 (7)	30.7	27.7 (slight HS) – 30.4 (moderate HS)

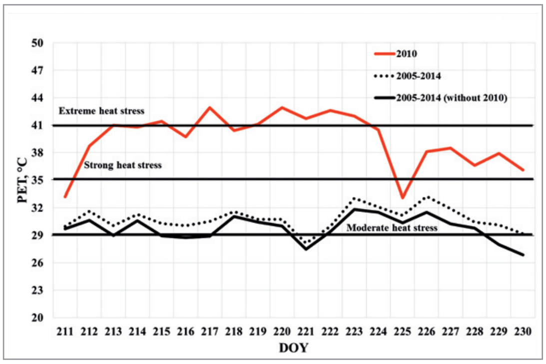

Figure 3. Temporal pattern of PET values at 12:00 UTC during the 20-day heat wave in Kharkiv from 30 July (DOY: 211) to 18 August 2010 (DOY: 230) and mean PET values during the period 2005–2014.

Slika 3. Vremenski niz vrijednosti PET-a u 12.00 UTC tijekom dvadesetodnevnoga toplinskog vala od 30. 7. (211. dan u godini) do 18. 8. 2010. (230. dan u godini) u Harkovu u usporedbi sa srednjom vrijednosti PET-a za razdoblje 2005. – 2014.

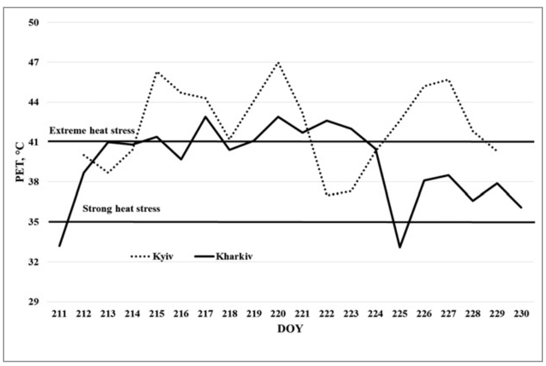

Figure 4. Temporal pattern of PET values at 12:00 UTC during the heat wave in Kharkiv and in Kyiv from 30 July (DOY: 211) to 18 August 2010 (DOY: 230).

Slika 4. Vremenski niz vrijednosti PET-a u 12.00 UTC tijekom toplinskog vala od 30. 7. (211. dan u godini) do 18. 8. 2010. (230. dan u godini) u Harkovu i Kijevu.

The analysis of maximum daily air temperature for 30 July–18 August 2010 shows that, unlike the PET values, the temperature values in 66.7% of cases were higher in Kharkiv than in Kyiv during the HW. The values of the posi-tive difference ($\Delta t_{Kh\text{-}K}$) varied from 0.3°C to 6.6°C on some days. However, it is common knowledge that human thermal perception is formed under the influence of a number of factors of the outdoor environment, and does not depend on air temperature alone. The main meteorological parameters affecting heat perception are air temperature and humidity, wind speed, and solar radiation (the latter factor is especially important during the summer season, and it can quite often be taken into account indirectly through cloudiness when calculating bioclimatic indices).

Analysis of the wind regime in Kharkiv and Kyiv during the studied HW episode reveals certain differences. Wind speeds of 1 to 5 ms^{-1} in Kyiv and 1 to 8 ms^{-1} in Kharkiv were recorded at 12:00 UTC during this period. The values of differences ($\Delta t_{Kh\text{-}K}$) are mostly positive, reaching 5 ms^{-1} on some days. The values of $\Delta t_{Kh\text{-}K}$ were negative only twice, but the excess of wind speed in Kyiv as compared to Kharkiv was only 1 ms^{-1} in both cases.

Relative humidity is an important environmental factor that can have a significant effect on human skin temperature and thermal sensation. Under extreme heat conditions, higher humidity can cause a negative effect on human thermal comfort, since high air humidity restricts evaporation from the surface of the human body, increasing the negative effects of heat. Significant differences have been identified in the air humidity values in Kyiv and Kharkiv at 12:00 UTC during the HW episode. In most cases, the air humidity was higher in Kyiv; on some days, this difference reached 24%. During the heat wave episode, air humidity was higher in Kharkiv than in Kyiv only on three days (the differences were small and did not exceed 4%).

Cloudiness has an indirect impact on thermal human perception (influencing solar radiation intensity and its effect on the human body). Analysis of the cloud cover regime in Kharkiv and Kyiv during the HW episode shows some differences. In most cases, cloud cover values were higher in Kharkiv than in Kyiv. The differences range from 1 to 6 octas.

Thus, the analysis of the weather conditions during the HW in late July/early August 2010 in Kharkiv and Kyiv confirms once more that human thermal perception (and, accordingly, PET values) is influenced not only by air temperature, but by a complex of environmental parameters.

4. CONCLUSIONS

This is the first study for Kharkiv based on the modern thermal index, which relies on the human body energy balance. The obtained results show that heat stress prevails during the summer months in Kharkiv (65.7% in June, 84.6% in July, 77.1% in August). The mean frequency of comfortable weather varies from 12.6 to 25% in different months. During heat wave cases in Kharkiv, severe heat stress was recorded on 51.4% of days, while moderate heat stress was recorded on 37.4% of days. Days with extreme heat stress were recorded only during the HW in August 2007 and during the HW in July-August 2010, reaching 7.5%. The last event was the longest and most intense in Kharkiv since 1936; daily PET values at 12:00 UTC during this HW ranged between 38.7°C and 42.9°C, which is significantly higher than the ten-year (2005–2014) averaged PET values for each of these days.

The findings obtained in this study can be used to establish a Heat Health Warning System, to plan adaptation measures for heat stress (especially during HW cases), and to help plan business and tourist visits to Kharkiv.

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